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Multi-criteria Decision Based on Safety Requirements in Water Plants

L. Cveticanin[1], S. Opricovic[2]

Obuda University, Nepszinhaz u.8, Budapest, Hungary

University of Belgrade, Bul. Kralja Aleksandra 73, Belgrade, Serbia

[1]cveticanin@uns.ac.rs

Abstract

In this paper a linguistic multi-criteria method is applied for making decisions in a water plant to provide the safety operation. If the vibration level of pumps is higher than the limit values prescribed by corresponding standards and, besides, the vibration has the tendency to increase, it is necessary to act, but not to perturb the water supply. Alternatives for acting are: to substitute the pump with a new one, to change the bearings, balancing of the pump's rotor, to rearrange the pumping regime, to fasten the pump construction or to intensify vibration and temperature monitoring of the layers. Which of these actions will be applied depends on the criteria of operation safety, safety of operators, increase of production efficiency, cost of action, in which season of year had happened, is the action necessary and it is necessary to be done instantly. Opinion of experts in field is usually different. The aim of the paper is to give a method for giving the optimal decision due to the mentioned criteria. For these purposes the SofverLingV is developed based on linguistic information. The obtained results agree with those obtained with Software VIKOR which was based on numeric description of the problem by experts. The suggested method is very convenient for application.

Keywords

Pump Vibration; Operator Safety; Operation Safety; Linguistic Software for Multi-Criteria Decision

Introduction

One of the most important tasks of the water plant is to provide continual and steady water supply independently on the season: winter or summer. Satisfaction of this requirement directly depends on the operation ability of pumps which are the main working machines in the factory. Namely, if there are some malfunctions and troubles with pumps the operation quality of the water plant will decreases. Propriety of pumps is monitored by measuring of vibration. This method is convenient as the data are obtained without stopping of pumps operation and the cost of investigation for measuring is not high [1-7]. Range of allowed vibration of pump operation is strictly prescribed. If the level of vibration is higher than it is allowed, reparation or modification in pump operation is necessary. To make decision on what to do is not always easy due to many uncertainties connected with measuring but also pumps properties and its behavior. There are many possibilities to act but the optimal has to be determined. Usually, not only one but a few engineers, technicians and even managers are included in making decisions. All of them have their own opinion and these are applied for making decisions. To improve the process of deciding, multi-criteria decision programs are developed. Since 1970 a significant number of software has been introduced for problem solving [8-10]. Roughly speaking, making decision consists of the following procedures:

- Generating alternatives
- Establishing criteria
- Evaluation of alternatives
- Assessment of criteria weights
- Application of a ranking method.

Alternatives are evaluates according to established criteria depending on the objectives of the problem. Evaluation of alternatives is performed according to each criterion from the set of established criteria. In the most of mentioned software the input values are given in numeric form.

In this paper an extension to the previous programs is made by introducing the linguistic description of experts' opinion. Namely, a new software named LingV is developed which is connected with the already applied software VIKOR [11-16] for multi-criteria decision. Two additional software are incorporated: GroupV-excel for calculation of linguistic information given by experts and the Vikor.p-Exel which is part of the previously developed software VIKOR.Software makes available to include linguistic uncertainties of experts and to transform them in numeric values [17]. The obtained compromise solution of multi-criteria decision is a feasible one which is the closest to optimal.

In this paper the mentioned multi-criteria decision method is applied in the water plant where the existence of increased pump vibration signifies the problem of safe operation. This paper contains five sections. After introduction, alternatives for acting are generated. Six alternatives are discussed. In Section 3, the criteria for decision are established. Seven various criteria are considered. In Section 4, experts' estimation and evaluation of alternatives based on criteria are given. Ranking of alternatives is given. This paper ends with conclusions. In the Appendix a Questionnaire is added.

Generating Alternatives

Generating alternatives is done with the aim to provide safety operation of the water plant taking into account the safety of operators and the efficiency of water production. Vibration of pumps is measured. Four groups of vibration level are prescribed: good, satisfactory, allowed and disallowed. If the level of some pumps is inside the third group, it is an alarm that some changes in the system have to be done and that the safety of operation is perturbed. We suggest the following alternatives:

A1. Vibration and temperature monitoring
A2. Strenghten-the pump construction
A3. Balancing of pump
A4. Bearing substitution
A5. Pumping regime variation
A6. Pump substitution with a new one

The first alternative is to intensify the monitoring of vibration of pumps, especially those which are in the third group of vibration and to make the tendency of vibration diagram. Besides, it is suggested to monitor the temperature of the bearings of the most important pumps. It gives us additional information about the working properties of the system. One of alternatives is to stabilize the construction on which the pump is mounted. This alternative is sometimes very efficient as it does not require the working process to be stopped. Usually this operation changes the rigidity of the system and changes the frequency of vibration. Unfortunately, sometimes this operation is not possible to be because the position of the pump or the additional strengthen does not give the optimal effect. The third alternative is to balance the rotating part of pump. It requires the pump to be excluded from the production process. Sometimes, this is not allowed due to the production diagram. The unbalance of the pump is usually caused by long-time work in the cavitation regime and the shovels of the pump are partly destroyed. As the water production is a continual process (water supply is necessary during the whole year) and the general repair of the water plant is rare, very often the pumps' bearings are working longer than it is optimal. The wear of bearings causes increasing of vibration level. As an alternative for vibration decreasing the bearing change is suggested. The fifth alternative is to change the regime of work of the water plant. It usually means that water flow is decreased. Unfortunately, it is not the most proper way to eliminate vibration and increase the operation safety. Finally, the sixth alternative is to substitute the rotor pump with new one with the first group of vibration level. This solution is the best, but it is the most expensive way to solve the problem.

Establishing Criteria

We specify criteria for decision of experts, if vibration levels of pumps in the water plant are higher than prescribed ones. Following seven criteria are assumed:

F1. Cost of action
F2. Operation safety
F3. Necessary action
F4. Urgency of action
F5. Operation efficiency
F6. Steady operation
F7. Safety of operator

One of criteria for making decision is the cost of action. Namely, the cost of alternative differs. Alternative of total repair of pumps is the best, but is the most expensive and the cheapest action is the change of pumps working regime, if it is possible.

Alternative which is selected has to supply safety for the water plant and also the operator which acts.

High vibration level of the pump may signify the failure in the rotor part of the pump, for example, the crack on the pump shaft or shovel. It may cause very serious damages of the whole pump and even to destroy them. Then, safety of operator is imperiled. To ensure the operators safety is also one of criteria for judging. Based on the report about the increased vibration level, experts have to decide if some action in the case is necessary or not. It is also one of the criteria how to solve the problem of high vibrations of pumps. Urgency of action is also one of the very important criteria for decision. Some of alternatives can be applied immediately and other requires more time. Which alternative to use depends on the operation efficiency and requirements for steady operation, too. Steady operation of the water plant even in the summer period, when the water spending is the highest, is one of the most important requirement for giving decision about alternative.

Experts Estimation and Evaluation

Refer linguistic information is converted by scaling into numeric values, for the assumed scale. Converted values are calculated by the method of averaging. Namely, replies of experts were linguistics and are transformed into numerical values. Estimates of criteria I - irrelevant, R - relevant, M – important are converted into following numeric values: I=1, R=2 and M=3. Applying the software GroupV-Excel, due to the formulation for group estimation it is (See [18,19]) ,

$$G_p = \sum_{g=1}^{E=9} \frac{g_{ep}}{E} \ ,$$

Where G_p is the total result for the p-th criteria, g_{ep} is the converted linguistic estimate of the e-th expert for the p-th criteria and E=9 is the number of experts. In Table 1, the averaged weights and the normalized weights up to the sum 1 are shown.

TABLE 1. AVERAGED AND NORMALIZED WEIGHTS OF CRITERIA BASED ON EXPERTS' ESTIMATION.

Criteria	F1	F2	F3	F4	F5	F6	F7
Averaged Weights	2.11111	3.00001	2.44444	2.55556	2.22222	2.44444	2.88889
Normalized Weights	0.11949	0.16981	0.13836	0.14465	0.12579	0.13836	0.16352

Due to the opinion of experts, the most important criteria are F2 and F7, i.e., operation and operators safety. Nevertheless, the consensus is that the importance of the safety operation of the water plant is indisputable.

In the Questionnaire ad it.3, experts estimated linguistically alternatives A1-A6 according to the given criteria F1-F7. We assign to the estimates the following numeric values: EB=1 - extremely bad, VB=2 - very bad, B=3 - bad, A=5 - average, G=7 - good, VG=9 - very good, E=10 – excellent, and apply them in calculation of results of expertise. In Table 2, the normalized weights from Table 1 and the values of criteria functions obtained by applying the software Group V-Excel are shown.

Using the data in Table 2, ranking of alternatives A1-A6 is obtained. Values of normalized weights and values $\left|f_{ij}\right|_{n,J}$, where f_{ij} is the value of the i-th criteria function for j-th alternative, n=7 is the number of criteria and J=6 is the number of alternatives, which are the input data for the software VIKOR.p Excel. Calculation gives the

following rank of alternatives:

TABLE 2. NORMALIZED WEIGHTS AND VALUES OF CRITERIA FUNCTIONS BASED ON ESTIMATION OF EXPERTS

Criteria	Extr.	Norm. Weight	A1	A2	A3	A4	A5	A6
Cost of action	Max	0.119	7.3333	5.1111	6.1111	5.1111	7.6667	5.2222
Operation safety	Max	0.170	8.1111	5.8889	7.0000	7.1111	4.6667	7.8889
Necessary action	Max	0.138	8.4444	3.2222	6.7778	7.2222	8.0000	5.7778
Urgency of action	Max	0.145	7.5556	5.4444	6.5556	7.5556	7.4444	4.7778
Operation efficiency	Max	0.126	8.7778	4.1111	8.8889	7.5556	5.1111	8.6667
Steady operation	Max	0.138	8.7778	5.7778	8.8889	8.4444	5.1111	8.7778
Safety of operator	Max	0.164	9.3333	4.8889	7.8889	7.1111	5.8889	8.4444

A1 (0.00) Vibration and temperature monitoring
A3 (0.33) Balancing of pump
A4 (0.49) Bearing substitution
A6 (0.78) Pump substitution with a new one
A5 (0.78) Pumping regime variation
A2 (0.98) Strenghten-the pump construction

Where ranking is given based on the value Q given in brackets. Result obtained with VIKOR.p Excel is that the alternative solution A1 is the compromising one.

Let us compare the obtained ranking list with that obtained by experts. The referred values are given as a matrix with $\left|r_{ej}\right|_{E,J}$, where r_{ej} is the rank of the e-th expert for j-th alternative, E=9 is the number of experts and J=6 is the number of alternatives. The resultant $rank_j$ for the j-th alternative is the averaged arithmetic value

$$rank_j = \sum_{e=1}^{E} r_{ej}/E \,, \qquad j=1,2,\ldots,6.$$

Due to this formulation, the following range list is obtained:

A1 (2.22) Vibration and temperature monitoring
A3 (2.78) Balancing of pump
A4 (3.44) Bearing substitution
A5 (3.44) Pumping regime variation
A2 (4.44) Strenghten-the pump construction
A6 (4.67) Pump substitution with a new one

In the brackets is the middle value of the range of the alternative. Experts give the priority to following alternatives:

A1 (2.22) Vibration and temperature monitoring
A3 (2.78) Balancing of pump

Comparing the result of ranking with previously obtained ones, it is evident that they are similar.

Conclusions

In this paper the linguistic multi-criteria decision method is applied for solving the safety operation of the water plant. Perturbation in water plant operation is evident due to increased vibration level of pumps. Six alternatives for improving the working properties of the factory are generated and seven criteria are suggested for making decision. A Questionnaire is formed and experts are tested. It is important to mention that evaluation of the criteria depends on experts' opinion and the subjectivity is not possible to be avoided. Linguistic replies of experts are transformed into numeric description applying the newly developed software. The input values are applied for making a multi-criteria decision.

It is concluded that due to the opinion of experts, the most important criteria are operation safety and operator safety. Nevertheless, the consensus is that the importance of the safety operation of the water plant is indisputable. Besides, the result obtained by applying of the multi-criteria software and expert opinion is to neglect the problem

of increased pump vibration is to introduce the continual vibration monitoring and additional measuring the temperature of bearings which will give prediction of pump behavior. The second suggestion, which is also very efficient, is to stop the pump and balance the rotor. Ranging decisions for acting are very useful for the person who is responsible for the water plant.

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APPENDIX

QUESTIONNAIRE

1. Rank of alternative actions for the case of enhanced vibration level by introducing numbers from 1 to 6 (the best rank is 1):

A1. Vibration and temperature monitoring
A2. Strenghten-the pump construction
A3. Balancing of pump
A4. Bearing substitution
A5. Pumping regime variation
A6. Pump substitution with a new one

2. Estimate the criteria as: I - irrelevant, R - relevant, M – important:

F1. Cost of action
F2. Operation safety
F3. Necessary action
F4. Urgency of action
F5. Operation efficiency
F6. Steady operation
F7. Safety of operator

3. Estimate alternatives as: EB - extremely bad, VB - very bad, B - bad, A- average, G - good, VG - very good, E – excellent:

Criteria - Alternatives	A1	A2	A3	A4	A5	A6
Cost of action						
Operation safety						
Necessary action						
Urgency of action						
Operation efficiency						
Steady operation						
Safety of operator						

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